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[1] Shravani Chapala
[2] Narasimham R.L.
[3] Tulasi Ram Das G
[4] G. Sree Lakshmi

PV and Wind Distributed Generation System Power Quality Improvement Using Modular UPQC

Abstract: - Today reliability and power quality are the two terms which influence the economic growth of any country. The current variations are one such power quality issue which affects power system. The root cause of these current variations as harmonics is due to the intensified usage of nonlinear loads. Active power conditioners can reduce current harmonics (SAPFs, SEAPFs, UPQCs, IPQCs). To be more specific, SAPF consists of a DC synchronizing Capacitor and a voltage source converter. In voltage source converters, the power semiconductor devices are switched using a Hysteresis Band Current Controller (HBCC). Series reactive current (SRC) injection is used for voltage compensation, and a proposal for using power quality (PQ) theory to produce reference currents to inject at the site of coupling for current reduction is made. By using pulse-width modulation and hysteresis as switching mechanisms, the UPQC will function in the presence of various disturbances, including phase-to-ground faults, non-linear loads on the grid side, and non-linear loads in parallel with the sensitive load. The functioning of the Unified Power Quality Controller (UPQC) is dependent on the voltage available across the capacitor in the dc connection; nevertheless, it is capable of compensating for all these issues. With a steady voltage applied to the capacitor, it performs well. Here an attempt is made to combine solar and wind generation stations with modular UPQC to enhance power quality issues of concern. Simulations were performed in MATLAB/SIMULINK.

Keywords: PV. Wind, Power quality, UPQC, MUPQC.

I. INTRODUCTION

Power consumption in the real world is growing exponentially. All of society's most fundamental requirements, as well as the most sophisticated industrial operations, require electricity. As it is, the current power system struggles the most when faced with the challenge of providing continuous, huge electricity. The use of distributed generation and its subsequent integration into the grid (also known as dispersed generation, decentralized generation, and embedded generation) into the power system, we can guarantee that consumers will always have access to electricity. "Distribution generation" refers to energy that is produced by a customer at the client end and could be connected to the distribution networks. The public will have access to the electricity produced by these distributed sources once they have been appropriately integrated into the grid. Many challenges are brought upon the grid because of incorporating DGs into it. Distributed generation (DG) integration, load instability, fast changes in loads, and electronic equipment all have a negative effect on power quality in the main grid.

These harmonics are being introduced into the utility by the widespread usage of converters in modern generators and transformers [1]. Harmonics from power electronic converters in wind power plants must be studied because of their importance to plant production [2]. By allowing nonlinear loads to be used as consumers to generate and inject harmonics in the demand side of the power system, UPQC can be taken beyond its theoretical confines and implemented as a practical means of improving power quality. UPQC has been used in two distinct ways, and both are considered in [3], which examines the scenario of UPQC's link to DGs. The DC connection is made in series with the DG unit and the data is analyzed if an abnormality is detected. Total harmonic distortion (THD) analysis shows that the four-wire approach described in [4] significantly reduces THD on the voltage and current, with THDv=2.47 and THDi=4.36 for the former and latter, respectively. Since the neutral wire influences all four wires, controllers in four-wire systems will be more difficult and will have worse performance than in three-wire systems (as was the case in this investigation). Modifying the harmonics with esoteric control schemes is described in [5]. The proportional (KP) and integral (KI) gains of such a PI controller should be adjusted for peak efficiency. Controllers integrated into linear electric power systems typically undergo KP and KI value tuning. Electricity transmission cables are regularly disrupted by voltage and frequency changes. The term "voltage fluctuation" refers to changes in the magnitude of the voltage. Short-lived energy spikes are called transients [6].

Nonlinear loads cause distortions to the voltage or current waveform known as harmonics. One other major PQD is a "long term voltage interruption" (Sarangi, 2020) [7]. Short-term drops in voltage or load current, lasting milliseconds to seconds, are what we mean by "trouble" here (Ma et al., 2021) [8]. Nonlinear loads (NLs) are becoming increasingly common in these networks, allowing utilities to reduce power consumption by cutting off inefficient, high-load clients. Electronic front ends make these NLs more efficient overall, but they also produce a

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[1] *Corresponding author: Dept. of EEE, CVR College of Engineering Hyderabad, India, and Research Scholar, JNTUK, india
[2] Dept. of EEE, Rtd. Professor, Andhra University, India
[3] Prof. Emeritus, Dept. of EEE, JNTU, Hyderabad, India.
[4] Dept. of EEE, CVR College of Engineering Hyderabad, India.

significant increase in distribution system harmonics. To improve power quality, transmission networks use FACTS devices, whereas distribution networks employ CPDs. The following criteria can be used to categorize DSTATCOM, DVR, and UPQC topologies: three factors: (1) the converter type, (2) the power electronics switching device configuration, and (3) the distribution network (3P3W and 3P4W). Isolated systems and non-isolated systems are distinguished by the transformers used for compensating for the neutral current and the voltage source converter, respectively. Common transformer configurations include the star-delta, zigzag, T-connected, and star-hexagon topologies. This section discusses a few approaches to reducing PQ, including STATCOM, UPQC, and UPS [9]. Whenever there is an issue with the voltage on the power grid, DSTATCOM is involved. The controller receives readings of all voltages and currents and compares them with set parameters. The power converter's primary semiconductor switches (IGBTs) are controlled by switching signals generated by the controller [10].

The ideal locations of the D-STATCOM and DG were calculated using a variant of the cat swarm optimization (CSO) algorithm developed by Bagheri Tolabi et al. (2015) [11]. These alterations are being made to reduce copper losses and provide a more uniform voltage across the board. By using the point estimate method, Akbari-Zadeh et al. (2014) [12] discussed the optimal placement of D-STATCOMs to reduce active power losses and voltage deviation for uncertainty loads (PEM). For the IEEE 30-bus network, Bagherinasab et al. (2013) [13] proposed a hybrid GA and ACO based on the utilization of three D-STATCOM nodes. Limiting energy waste is the primary motivation for this research. Three D-STATCOM are optimally located with the help of ACO, and the reactive power provided or consumed by each device is determined with the help of GA. Kamel et al. (2019) [14] [17] use a clustering technique to determine where to put DG and D-STATCOM, much as Bagheri Tolabi et al. A crucial energy management method for off-grid cellular networks with hybrid power sources like solar PV arrays and diesel generators (DG) improves energy efficiency (EE) and reduces fuel usage [18] [19].

II. UPQC INTEGRATION

Custom Power Devices (CPD) like UPQC are gaining prominence to enhance power quality in DG or microgrid systems [9]. The two DC components of UPQC, the series active filter and the shunt active filter, are shown in series with a common DC capacitor [10]. Voltage fluctuations, spikes, flickering, voltage imbalance, and harmonics can all be reduced with the use of the UPQC series circuit. It maintains balanced, distortion-free load voltages by injecting voltages at regular intervals. The low power factor, load harmonic currents, load unbalance, and other consumer-caused power quality issues are reduced by the shunt component. Sinusoidal, in-phase currents are injected into the ac system to match the waveforms of the source voltages.

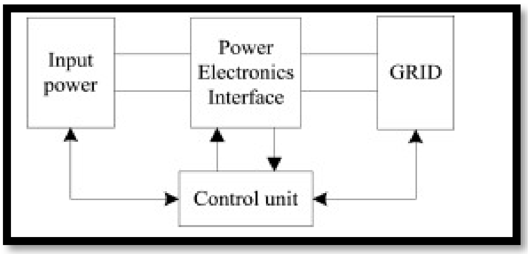


Figure 1. Grid connected RES system structure.

UPQC is seen in Figure 1. It consists of a common DC capacitor shared by two active power filters, one series (APFse) and one shunt (APFsh), which are coupled back-to-back on the dc side. Reducing supply-side disturbances such voltage sags/swells, flicker, voltage imbalance, and harmonics is the job of the UPQC's series component. It injects voltages to keep the load voltages balanced and distortion-free, at a level that is desired. Reduced consumer-caused power factor, load harmonic currents, load imbalance, and other current quality issues are the responsibility of the shunt component. To bring the source currents into phase with the source voltages and make them balanced sinusoids, it injects currents into the ac system. The APF controller, both series and shunt, is important to UPQC's entire operation. The UPQC controller is shown in Figure 2 as a basic functioning block diagram.

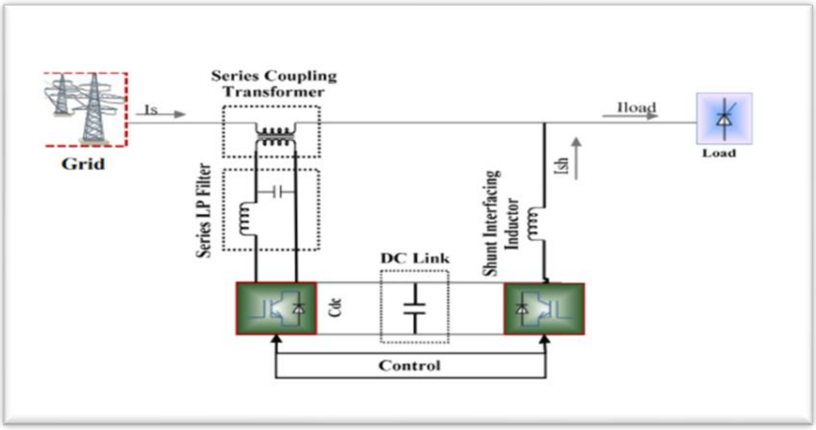


Figure 2. Configuration of UPQC System

Implementing a UPQC in the dispersed generating network can help with a variety of power quality issues on the transmission and distribution grid. We have explored DC-Linked and Separated DG-UPQC systems as part of our efforts to integrate UPQC with DG systems. An example of a proposed architecture involves connecting DG sources to a DC connection in the UPQC, as depicted in Figure 3.

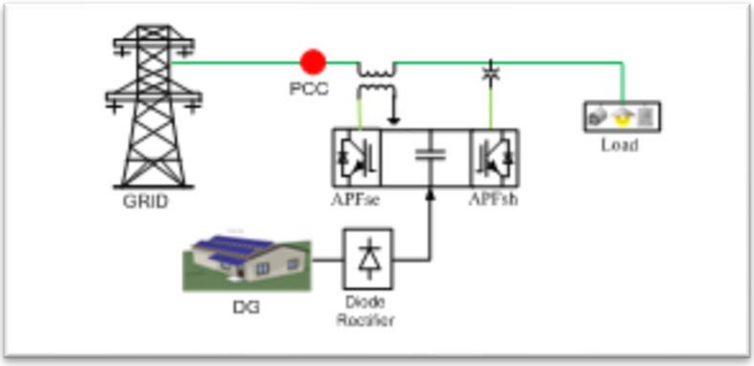


Figure 3. Upgrading the Quality of Current using DG and a Direct Current Link

This configuration works equally well as part of a larger network or on its own. Power from DG is supplied to both the source and the loads when the system is in linked mode, but only the load when the system is in islanded mode (within its power rating). During blackouts, UPQC can inject power via DG to key loads for added redundancy. The system has all the advantages of UPQC plus the ability to compensate for voltage interruptions and inject power into the grid actively. It is possible that system operation could be impacted if DG resources are insufficient during times of electricity outage. For active power regulation between the grid and the DG generation, a series active power filter (APF) is required. When the UPQC and DG are utilised independently, the suggested system can lower the investment cost by about 20%.

III. CONTROL STRATAGY CONTROL ALGORITHM FOR SAPF

A. *Control algrithm for SAPF*

PQ theory, an easy and efficient control algorithm, is advocated as a standard for today's youth. These distinguishing characteristics of PQ theory are: For 3-phase electrical systems, it is the norm. Because it uses real-time data, it has a rapid response time and can adapt to changing conditions. Easily attainable mathematical conclusions (can be implemented by standard processors). In its simplest form, PQ theory is a method for detecting and dampening current harmonics. In a nutshell, it's a change from the 3-abc rotating frame to the 2-abc revolving. The primary principle is the worth filter, which extracts basic components. Further the reverse process of 2-Ø static frame to 3-Ø rotating frame gives the required reference signals. To develop the necessary reference currents, the source voltages and load currents are sensed. Fig 3.1 is an illustration of how the PQ theory is put into practice. For developing the necessary reference currents, the following source voltages and load currents are sensed.

$$\begin{bmatrix} v_{\alpha} \\ v_{\beta} \\ v_{0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_{a} \\ v_{b} \\ v_{c} \end{bmatrix} \quad (1)$$

Where, Vabc is 3-Ø supply voltages of rotating frame and Vαβ0 are 2-Ø supply voltages of rotating frame.

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

Where Iabc are 3-Ø supply currents of rotating frame and Iαβ0 are 2-Ø supply currents of rotating frame.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

The solutions to Equations 1 and 2 are shown in Equation 3. p here stands for active power while q for reactive power. An further categorization distinguishes them into AC and DC varieties.

$$p = \bar{p} + \tilde{p}$$
$$q = \bar{q} + \tilde{q} \quad (4)$$

Where $\bar{p}\ \bar{q}$ is a weighted average of p and q in DC, and $\tilde{p}, \tilde{q}$ represents a constant-power (AC) value of p and q. The resulting p and q values are then subject to the butter worth filter's control. The resulting p and q after the filtering action are used in the following equations to get the reference currents: In the first place, the 2- rotary currents are given by:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (5)$$

With

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} 0 \\ \bar{q} \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (6)$$

Where $\Delta = v_\alpha^2 + v_\beta^2$

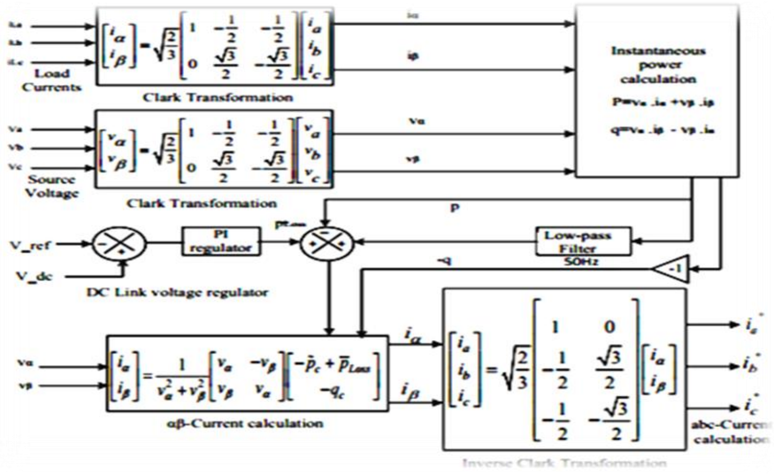
$$\begin{bmatrix} \tilde{i}_\alpha \\ \tilde{i}_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (7)$$

Where: $\tilde{i}_\alpha$ & $\tilde{i}_\beta$ are fleeting currents without a fundamental component. Here is how you may get the instantaneous 3- reference currents in a rotating 2- frame:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \tilde{i}_\alpha \\ \tilde{i}_\beta \end{bmatrix} \quad (8)$$

$$i\ error = i\ reference - i\ actual \quad (9)$$

The hysteresis controller in SAPF is responsible for producing the gate signals used by the VSI's IGBT switches.



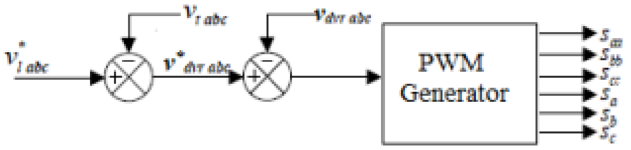


Figure 4. Shunt inverter Control diagram.

Regulation of the DC connection capacitor relies heavily on the accuracy of the controller's tuning. Current error signals are produced when reference currents (Iabc *) generated by the SAPF control unit are compared to injected filter currents (Ijabc) in the power grid. HBCC receives the erroneous current signal generated by this comparison and is given in figure 4. The hysteresis controller in SAPF is responsible for producing the gate signals used by the VSI's IGBT switches.

B. Control Algorithms for SeAPF

Voltage monitoring and standardization are performed using synchronous reference theory, a simple and efficient control method. The control method uses voltage measurements and sag/swell detection to derive reference voltages, which are then used to generate gating pulses. This filter uses a combination of phase-locked loop (PLL) and nonlinear adaptive phenomena to enhance signal breakdown and peak identification. When it comes to voltage compensation, which the SeAPF needs to handle, this theory is primarily intended for reference voltage generation. The consequences for this are evident in dq theory. Here, voltages are transformed from their original three-phase synchronous (abc) form into a more conventional, fixed (d-q-o) form. What this indicates is that p and q are independent variables that can be controlled independently of one another. Figure 5 depicts the SRFT's fundamental block representation. The DC link capacitor responds by injecting or sucking through the injection transformer based on the presence or absence of a sag or swell irregularity. This is a result of the DC link capacitor's mistake. The PI controller improves response time while decreasing both steady-state and transient errors. Afterwards, inverse Park's transformation is used to revert the output to the original signal. When all of these signals are added together, they form what is known as the Reference signal. (Vsa*, Vsb*, VSI* =Vsabc*). When power quality issues arise, the equipment is protected by a well-designed control system, which also eliminates any disturbances caused by the equipment itself or the power system.

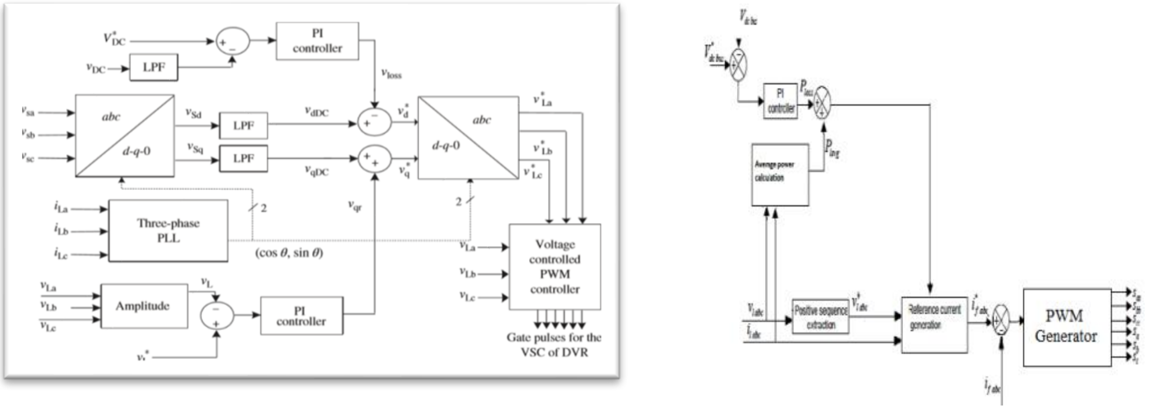


Figure 5. Shunt inverter Control diagram.

C. Control of UPQC

The control unit UPQC employs a hybrid of SAPF and SeAPF methodologies for its own control purposes. Specifically, SAPF is used in conjunction with PQ theory to provide a voltage reference signal, while SeAPF is used in conjunction with SRF theory. In this combined fashion, UPQC is utilised. Shunt APF using HBCC to create the gate pulse and Series APF using PWM to create the gate pulse. UPQC makes use of both together. Figure 6 shows the block design of the 3-phase 4-wire Wind-PV-UPQC power circuit that was employed in the simulation experiments. It is made up of two inverters that are linked back-to-back and have three levels: neutral point clamped (NPC). The two PWM converters, one for parallel and one for series, are connected to the LC and L filters, respectively, in accordance with the presumed double compensation techniques.

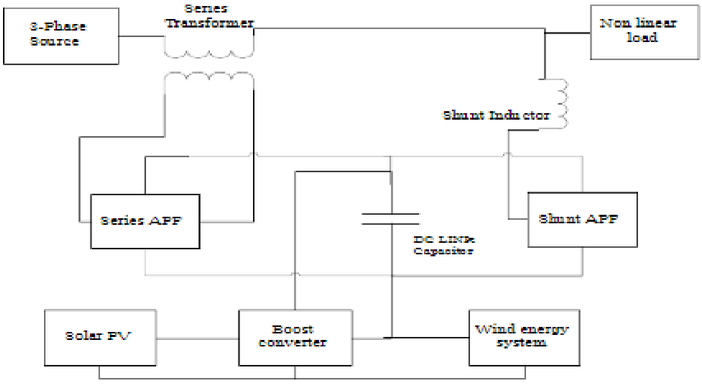


Figure 6. PV, Wind fed UPQC block diagram.

Shunt active power filters (SAPFs), series active power filters (SeAPFs), and unified quality power conditioners (UQPCs) are just a few examples of the many types of power conditioners available (UPQC), and the modular UPQC, are introduced briefly, along with the control algorithms that allow them to solve the PQ problems. The voltage/current reference signal generation theories considered for evaluation of PQ issues are as follows: The SRF-based active power series filter theory, the PQ theory for SAPF, the SRF theory for SeAPF of UPQC, and MUPQC are all part of the shunt active power filter PQ theory. The gating signal generation is done based on the following controllers: High-Bandwidth Current-Circulating Component (HBCC) for Shunt Active Power Filter, A power factor modulator is integrated into a series active power filter and HBCC for SAPF and PWM controller for SeAPF of UPQC as well as MUPQC.

IV. SIMUALTION RESULTS

Figure 7 displays the MATLAB/Simulink model of UPQC under nonlinear stress. Table 4.1 details the UPQC simulation system parameters. The references used to create Table 4.1's descriptions of each design feature. The UPQC was developed as a means of addressing these power quality issues; To cancel out harmonics in the source current, it injects compensatory currents into the line at the coupling point. When utility voltages drop, the UPQC steps in to supply the necessary compensatory voltages. When electricity utility transmission line conditions become anomalous, the cascaded DC link capacitor is activated. The power circuit, control unit, reference current generator, and gate signal generator for the switches included in the VSC of SAPF are detailed in the above section.

TABLE I. SIMULATION PARAMETERS FOR THE SYSTEM

Parameter	Specifications
System Voltage	415V, 50Hz
Line Impedance	L = 3mh, R = 0.0001Ω
Linear Load	RL = 50 Ω
Nonlinear load	RL = 50 Ω and L = 1mh
DC link Capacitor	C = 1200μF
DC link Voltage	Vdc = 600V
PWM switching frequency	10KHz
Hysteresis Band	H = +_0.5
Shunt VSI parameters	R= 2.5 Ω, L = 10mh, 6 IGBT’s
Series VSI parameters	C = 10μF, L = 8mH, 6 IGBT’s

It can be shown in Figure 8 that without any filtering action, the nonlinear load causes the source current waveform to be distorted by a total harmonic distortion (THD) of 26.78 percent shown in Figure 9 by acting as an efficient filter, SAPF is designed to reduce these nonlinearities in the source current.

In the system, a programmable phenomenon causes a voltage swell for (0.2 to 0.4) seconds, followed by a sag for (0.5 to 0.7) seconds. The load on the system is altered by more than 10% from the IEEE standard when a sag or swell is produced. The SeAPF will buck for (0.2 to 0.4) seconds, and then inject the appropriate voltage to maintain the system in its pre-sag/swell state for (0.5 to 0.7) seconds and is gven in Figure 10. The following shows how the power quality challenges can be addressed using a solar-wind hybrid station that resembles dispersed generation.

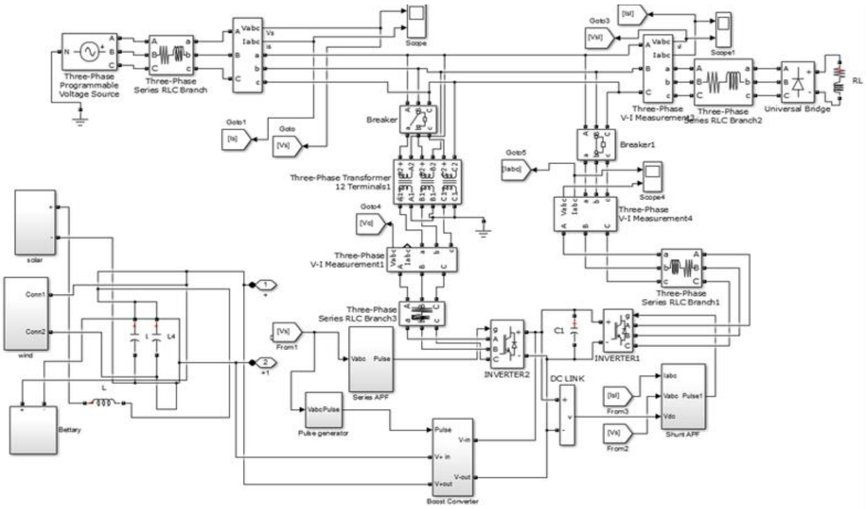


Figure 7. MATLAB/Simulink of UPQC to improve power quality.

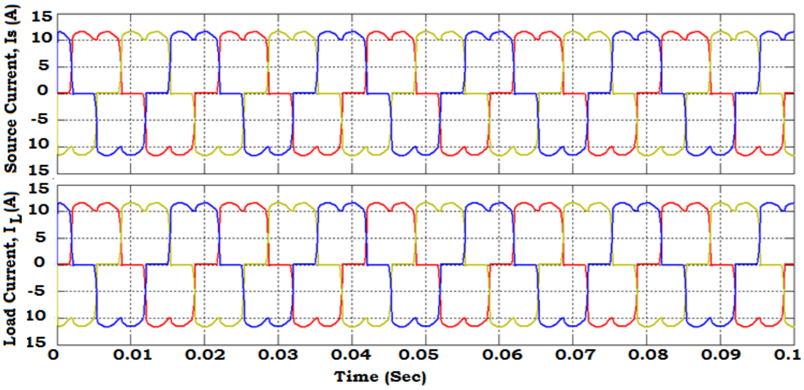


Figure 8. Nonlinear load current and source current

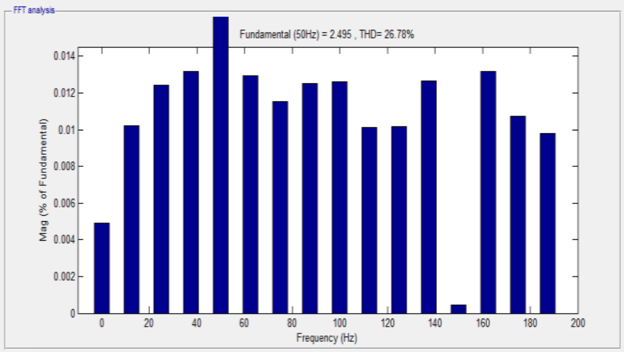


Figure 9. FFT analysis

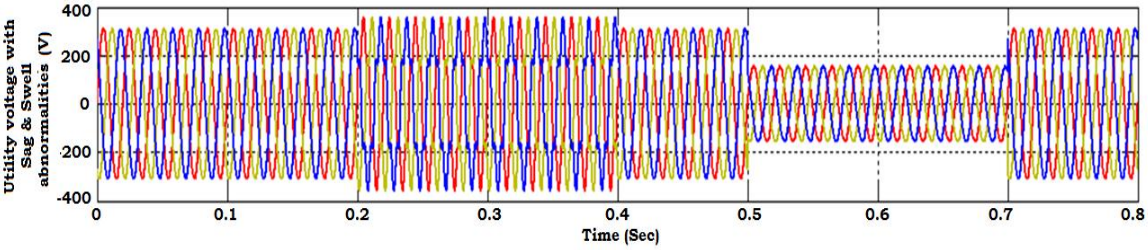


Figure 10. Voltage sag and swell.

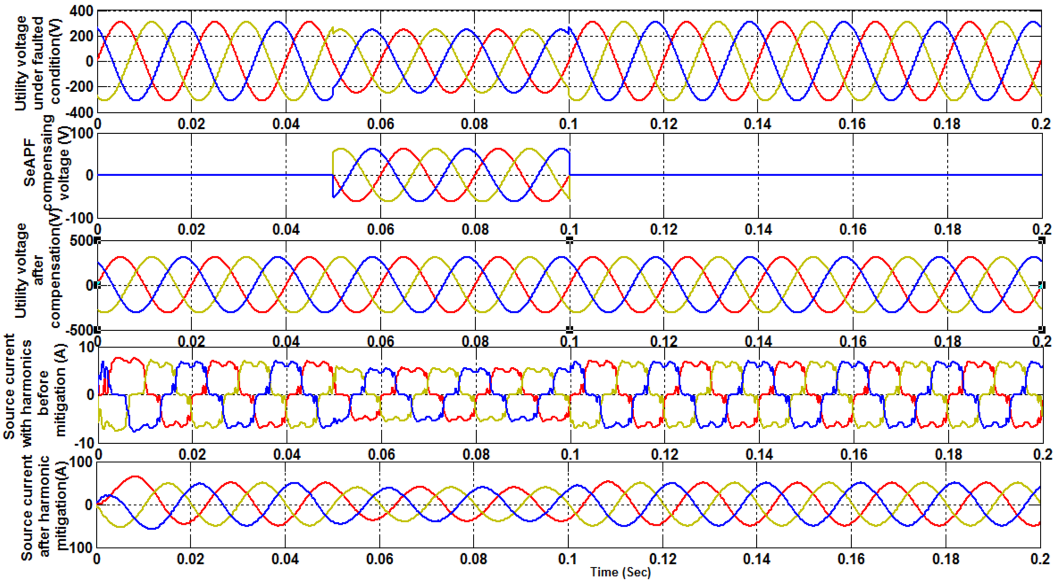


Figure 11. MUPQC dynamic Performance

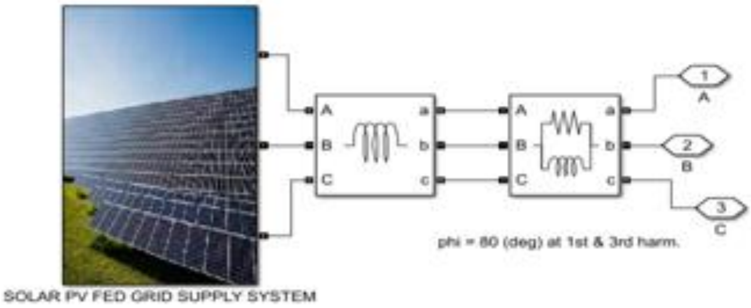


Figure 12. Solar PV system.

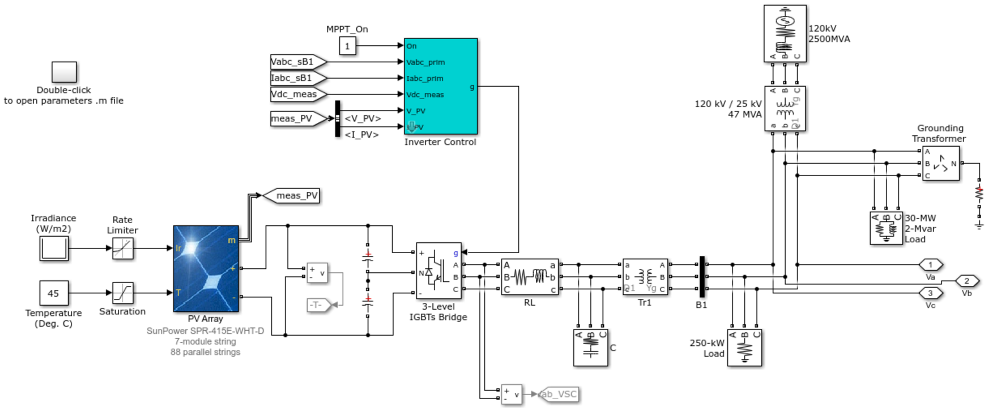


Figure 13. Solar PV fed supply system.

Figure 13 shows the converted solar PV grid supply to an AC grid supply. Figure 14 shows the Solar PV fed supply system voltage and the total input power that is available from the PV supply station in the Figure 15.

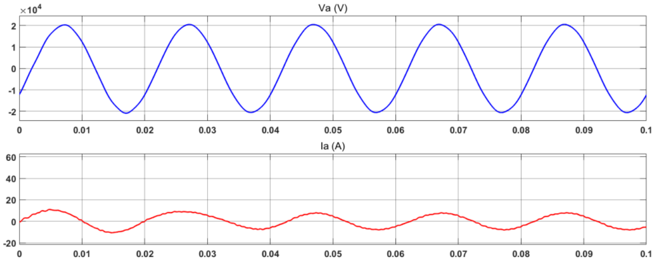


Figure 14. Solar PV fed supply system voltage and current.

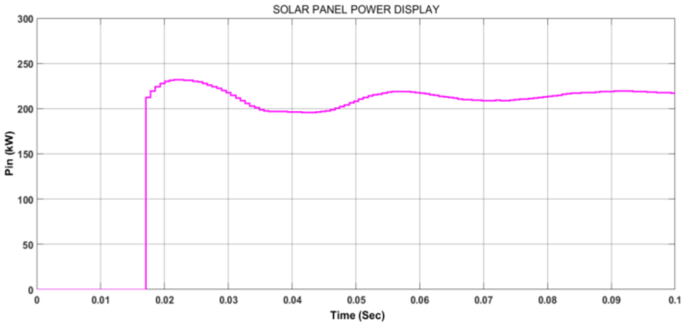


Figure 15. Solar PV fed supply power.

The Figure 16 shows the converted wind power grid supply, which is an alternating current grid supply. Figure 17 can show the total input power that is available from the PV supply station in the Figures 18 and 19.

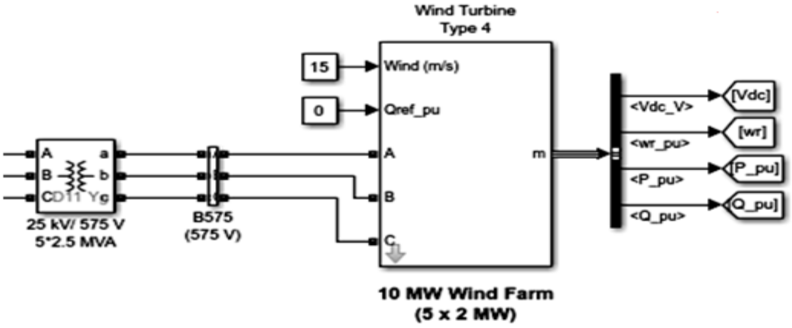


Figure 16. Wind fed system.

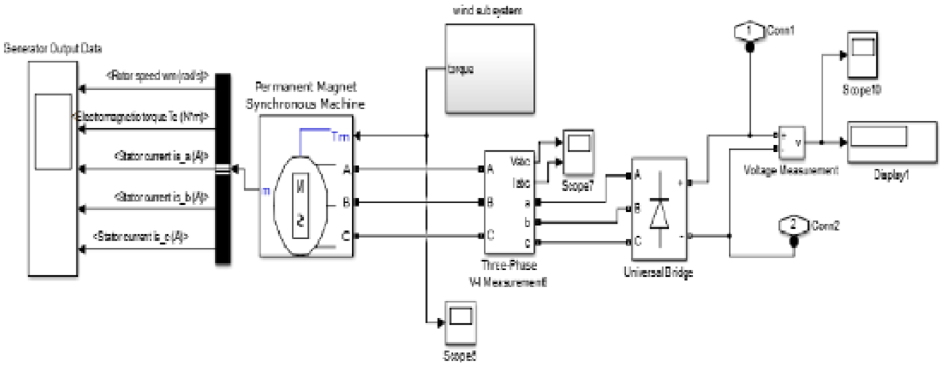


Figure 17. Wind fed grid supply system.

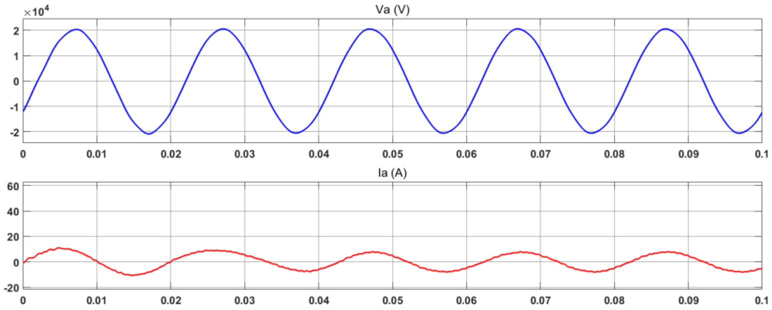


Figure 18. Wind fed supply station voltage and current.

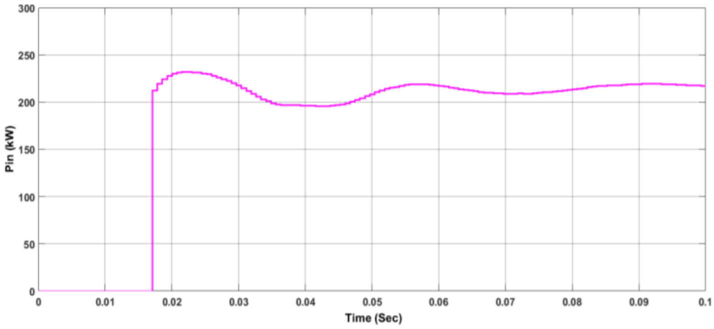


Figure 19. Wind fed supply power.

When there are disruptions in the power utility transmission line, the cascaded DC link capacitor is activated. In this case, an irregularity is generated by a programmable voltage source for 0.05 to 0.1 seconds, and the voltage is restored by the action of a capacitor during this time. Voltage fluctuations are mitigated by the DC connection capacitor. As far as we can tell, with KP1 = 0.05, KI1 = 0.2, KP2 = 10, and KI2 = 0.1, the source voltage THD is 2.01%, the source current THD is 8.37%, and the load voltage variation is 10%. Having an expert choose the values for the PI controller's KP and KI is common practice, however this is inefficient and overlooks the fact that nonlinear systems do not behave linearly. By fine-tuning the PI controller's KP and KI values, this restriction can be bypassed. Therefore, voltage sag and swell are corrected to nominal value with modular UPQC, and the THD is decreased to 1.5%, which is lower than the normal IEEE norm. With the PI controller gain parameters shown in Table 2, the voltage THD is lowered to 0.25 percent and the sag voltage error is cut down to 0.7326 percent. Gain values for the PI controller used in the considered intelligent system are as given below. Table 3. UPQC results compared to those obtained using the PI (an iterative method) and the suggested PSO algorithm.

TABLE II. PI CONTROLLER GAIN VALUES

Parameter Variable	Kp1	Ki1	Kp2	Ki2
PI	0.05	0.2	10	0.1

TABLE III. THD COMPARISON

Parameter Variable	Isthd%	Vsthd%	Vserror%
PI	1.4652	0.2442	0.7326

V. CONCLUSION

A modular UPQC (MUPQC) that has the potential to mitigate the heating effect of harmonic loads and restore voltage decreases resulting from the start-up of heavy equipment is developed. The integration of PE with grid has become feasible due to the rapid improvement of PE technology. Experiments have shown that the UPQC - DG can effectively handle any Power Quality problem. There is a vast uncharted territory of possible topological combinations of UPQC that might serve a variety of purposes. The effectiveness of the suggested method is assessed in relation to the standard PI-controlled UPQC. Therefore, in addition to the standard UPQC operations, the suggested approach may control the injection of active and reactive power into the grid and correct for voltage interruptions. Harmonic suppression and voltage sag compensation are two areas where the proposed MUPQC has been shown to excel above the standard PI controller. In this way, the simulation results support the claim that the proposed method is effective.

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